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LANSCE DIVISION TECHNOLOGY REVIEW

Advances in Low-Level Radio-Frequency Control System Design

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Staff members from the Spallation Neutron Source (SNS) Division and the Los Alamos Neutron Science Center collaborated on an upgrade of the low-level radio-frequency control system (RFCS), which performs a number of critical functions on the Low-Energy Demonstration Accelerator (LEDA). The RFCS has gone through several upgrades since 1988 when it was first developed for the Ground Test Accelerator (GTA). It was upgraded for the Accelerator Production of Tritium Project and is now being used on LEDA and modified further for the SNS at Oak Ridge National Laboratory. Each subsequent upgrade took advantage of state-of-the-art components and digital technology, allowing researchers to reduce the RFCS to a quarter of the size of its predecessors, yet with more features.

The RFCS primarily monitors and controls the radio-frequency (rf) fields in the accelerator cavity to within specified amplitude and phase requirements (field control functions); monitors the resonance frequency of the rf field in the accelerator cavity and takes actions to move the resonance frequency to the operating frequency (resonance control functions); monitors the high-power rf distribution system and quickly alerts the machine protection system of a fault or arc condition (high-power-protection functions); and distributes a phase-stable rf reference signal throughout the accelerator (frequency reference systems). The goal of our work is linked to the primary purpose of this unique system—that is, to minimize deviations in the rf field in the accelerator cavity from the operator-defined set points. The rf field must be at the right phase and amplitude to efficiently move beam through the accelerator.

System Implementation

Fig. 1 shows a block diagram of a typical RFCS. The dotted lines represent different VXIbus modules that perform the functions described above. The three klystrons used for the LEDA radio-frequency quadrupole have a single RFCS housed in a dedicated VXIbus "crate" that serves as a local processor for data-acquisition, system-monitoring, and real-time-event-processing tasks. The VXIbus interfaces with the experimental physics and industrial control system (EPICS) to send and receive information about the controls the in-phase and quadrature (I/Q), rather than the amplitude and phase, components of the accelerator cavity rf field. The I/Q field control was

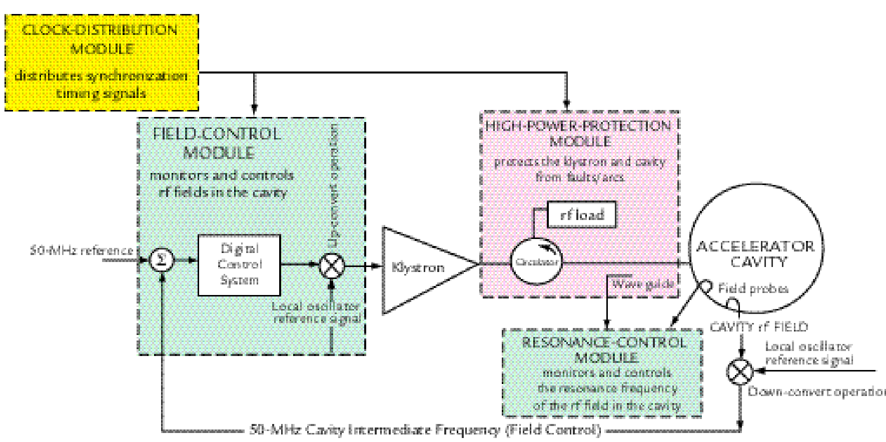

Fig. 1. *The colored blocks represent functions performed by the RFCS control modules. The clock distribution receives a 2.5-MHz reference signal; produces local oscillator (LO) signals (352.5 MHz and 755 MHz), an intermediate-frequency field, and an analog-to-digital-converter frequency, all of which are needed to down-convert rf frequencies and to sample I/Q (in-phase and quadrature) signal components; and translates timing signals from the master timer for synchronizing sampling data.*

way the RFCS originally suggested and implemented on the GTA's low-level RFCS. It has since become the standard around the world.

Field- and Resonance-Control Functions

The master-timing system, which serves as the source of all precision timing signals for the RFCS, transmits synchronous data-sampling signals to the clock-distribution module (CDM), which then passes these signals on to the other RFCS control modules. They use these signals to synchronously collect data on the system's operations. The field-control module continuously monitors the amplitude and phase of the rf field throughout the entire accelerator system on a pulse by pulse basis and then takes the necessary actions to compensate for any rf field perturbations detected. The resonance-control module continuously monitors the actual resonance frequency within the accelerator cavity via field probes and moves it to the set operating resonance frequency, and it maximizes the rf power that is amplified by the klystrons and then transferred to the accelerator cavity. It does this by calculating the difference between the design and actual resonance frequency of the cavity and then outputs the frequency error to EPICS, which forwards the error to the appropriate cavity tuner system. Sample data are sent to EPICS for diagnosis about the RFCS and its associated functioning. EPICS is used by the operators in the control room to monitor different parts of the RFCS, but the RFCS takes the appropriate actions, for example, performs calculations and corrects rf/resonance field perturbations, to keep the system running at the operator-set field frequencies.

High-Power-Protection Functions

The high-power protection module (HPM) protects the klystron and accelerator cavity from high-power rf faults that may occur by monitoring the system for excessive rf power at various test points and for arcs internal to the accelerator cavity. The HPM interfaces with the "outside world" for quick-response actions via a control system that provides the HPM with rf input and via the machine protection system that terminates the beam. If a fault condition is detected, the HPM quickly shuts down the rf carrier and alerts the machine protection system, which then terminates the beam.

Frequency Reference System

The purpose of the frequency reference system is to provide a phase-stable frequency reference at each control system. The frequency reference system provides two LO frequencies (352.5 MHz, 755 MHz) and a precision 2.500-MHz clock reference to the RFCS. The two LO frequencies are used to down-convert the 402.5-MHz (352.5 MHz + 50 MHz) and 805-MHz (755 MHz + 50 MHz) signals to a 50-MHz intermediate frequency in the accelerator cavity. The resulting 50-MHz signal is brought back to the RFCS for digitization and processing. The 2.500-MHz signal is used as the reference for the CDMs and is synchronized to the LO frequencies at each RFCS subsystem.

Great Strides Using Digital Technology

The field and resonance control modules rely on fast Complex Programmable Logic Devices (CPLDs) and digital signal processors (DSPs) optimized for real-time signal processing. The resonance frequency in the accelerator cavity is obtained from DSPs by sampling the forward and the transmitted rf-field signals from the cavity and calculating the cavity's rf-field admittance. The resulting resonance-frequency error is used to drive whatever type of resonance controller is in use, for example, a water-cooling method for normal conducting cavities or a mechanical tuner for superconducting cavities. The CPLDs perform the complex control functions required to keep the cavity field at its operator-defined set point. Operator interface with the HPM also provides the operator with the ability to control rf thresholds and the time duration of allowable fault conditions within the high-power rf distribution system. The GTA's low-level RFCS did not perform the HPM functions that the current RFCS upgrades do and yet it still consisted of three crates of electronics. By the end of the GTA program, we had incorporated some digital technology, which allowed us to reduce the size of the RFCS to two full crates. By continuing to take advantage of digital technology, we have made great strides in further size reductions with enhanced performance at reduced cost.

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